Web-based Visualization of Transportation Networks for Mobility Analytics

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ABSTRACT

Mobility analytics is a growing field with various use-cases. Specific tools for visual, spatial, and spatio-temporal analysis are not only important for trained professionals and experts of GIS, but also required by non-domain experts, such as urban planners, business managers, and private users. In this paper, a web-based visualization technique for network-based reachability analysis using reachability maps of multimodal transportation networks is presented.

CCS CONCEPTS

• **Human-centered computing** → **Geographic visualization**; *Web-based interaction*; • **Networks** → Network management.

KEYWORDS

web-based network visualization, multimodal transportation networks, reachability maps, location intelligence, mobility analytics, visual analytics

1 INTRODUCTION

Mobility describes the ability of people and goods to move around an area, and in doing so to access the essential facilities, communities and other destinations that are required to support a decent quality of life and a buoyant economy. Mobility incorporates the transport infrastructure and services that facilitate these interactions [3]. Mobility is a key requirement in economics, logistics, private life, as well as tourism and is faced with the general key challenges of traffic volume, traffic infrastructure, and traffic media. Mobility Analytics (MA) can be understand as a holistic approach to mobility information. Its data-driven approach combines real-time queries with visual analytics approaches with the aim of enabling predictive analytics with respect to mobility data. The potentials of MA are diverse, i.e., almost every spatial process can integrate this technology for optimization as well as to extend functionality and precision. It enables the automation of essential processes in spatial location benchmarking, a generic functionality for almost every area of application. Specific fields of applications ranging from real-estate location and object analysis, commercial location benchmarking, transportation infrastructure design and optimization, over logistics configuration, steering, and tourism tour planing as well as optimization.

Today, mobility analysis and visualization is often performed using Desktop GIS. Such systems exploit the computation power of desktop PC but posses limited applicability to everyday life, due to data availability and access, as well as expert domain knowledge required by a user. With respect to these restrictions, performing server-based reachability analysis in combination with interactive web-based reachability-map visualization has various advantages: (1) its usage is not limited to stationary desktop systems but available on a variety of devices, (2) potentially massive data sources are not required to be completely transmitted, stored, or managed, and (3) implementations based on web-services and WebGL [15] can be easily integrated into existing systems and visualization frameworks.

In contrast to existing reachability-map visualization concepts, this paper focuses on visualizing the travel time data directly on the respective transportation network features, rather than (possible generalized) polygons [9] or specific graph-layouts [16]. This enables a precise mapping of travel data to the geo-referenced transportation network. Real-time rendering complete transportation networks as scenery for data visualization in web-based applications is a performance critical task depending on the geometric complexity of the network and associated travel times. Using traditional visualization approaches using web browsers either faces users with a predefined, static filtering and mapping (raster data) or a notable computation-intense rendering process (vector data).

These two fundamental approaches covering filtering, mapping, and rendering web-based maps are widely established and have proven to be effective, but exhibit drawbacks. For example, data transmitted in pre-rendered raster *data formats* does not require any client-side processing prior to rendering, can be compressed as well as cached [6], and is used by major web-mapping services such as Google or Bing maps. However, one major disadvantage is the lack for client-side filtering and mapping without requesting a complete map tile reload. In contrast thereto, geodata transmitted using *vector formats* enable client-side filtering, mapping, and rendering. This client-side processing however introduces a major performance impact: both the data processing and rendering are usually performed on CPU using JavaScript (JS) algorithms. Recent approaches do support GPUs but lack functionality for client side vector data processing [8]. Thus, both approach changes in filtering (e.g., selecting a travel time threshold) or mapping (e.g., color mapping, line styles) would result in a complete data re-transmission, loading, and processing. To summarize, this paper presents a novel approach to interactively visualize high-detailed transportation networks in a web browser using (1) a client/server software architecture based of a vector tiling approach, and (2) interaction techniques specific to reachability maps for mobility analytics.

2 RELATED WORK

Visualization using Reachability Maps. Hansen defines accessibility as indicator for urban transportation systems [11]. He presents a method for determining accessibility patterns within metropolitan areas and defines accessibility as the potential of opportunities for interaction serving residents in urban areas. Armstrong compares accessibility information by converting a major road network into a reachability matrix representation [1]. The results facilitate evaluating the economic feasibility of airports in South Hampshire. When mapping time distances, the resulting space is often non-Euclidean and hardly map-able without distorting the geographic reference system. With respect to this, Muller presents a numerical approach for time-distance transformations of Edmonton and analyzes the resulting distortions [20]. The patent #US006317686B1 on *Method of providing travel time* claims a personal multimodal travel prediction and trip decision support system including traffic forecast maps, such as travel speed maps, travel time maps, and travel cost maps [23]. It uses contour lines to represent predictive minimum travel time from a selected origin.

TimeContours is a Java application that maps isochrones onto public transport and road graphs to display transportation costs with respect to the travel time required [25]. It discusses methods to display more than two dimensions on geographic maps such as isolines. It defines isochrones – isolines of the same time – as derivation of the in topographic maps more commonly used isohypses – isolines of the same height. A first web service for accessibility analysis proposes an Accessibility Analysis Service (AAS) based on standards defined by the Open Geospatial Consortium (OGC) [22]. A provided web application is presented as Java applet and receives reachability data in eXtensible Markup Language (XML) format. It computes an elevation model where the third dimension encodes the required travel time and compares different visualization methods such as buffers, convex hulls and isochrones to display the

results. A summary on different methods for providing accessibility maps (e.g., accessibility indices, anamorphosis maps or isochrone visualizations) are presented in [26].

Glander *et al.* present an accessibility map visualization technique with a focus on polygon-based approaches in the public transport domain [9], and raster-based distance transforms [21]. These both lack precision in display that is enabled by network-based approaches such as the one presented in this work. Further, Yin *et al.* present a web-based system for visualization of multimodal accessibility for multiple land-uses [28]. It highlights the importance of providing an easy to use web-interface as the users will not need to purchase or install software and therefore make the application accessible to a wider range of audiences. However, the visualization technique does not focus on the specifics of mobility network representations. In [13], the web-based accessibility mapping system SONA is presented that allows tourists in the city of Potsdam to explore reachable points-of-interest (POI) within a few minutes of walking time using a unique network-based display. However, the authors notice this visualization is only possible for small networks but highlight the advantages of mapping travel times directly onto the underlying transportation network. In [12], a full application stack is presented for providing a web-based AAS. An efficient generalization technique to render the map with detailed color-coded isochrones is required, due to the lack of performance, when visualizing larger transportation networks in a web client.

Web Applications for Mobility Analysis. Besides scientific work presented in the previous section, an overview of web applications displaying reachability maps is presented. Carden presents one of the first notable reachability mapping service for a web browser called the *Travel Time Tube Map* [4]. This Java applet renders the London tube map using its Euclidean geographic representation. Selecting nodes results in displaying static circular isochrones around the starting station and in the distortion of the network geometry to fit each station into the circles according to the travel time required. This application is limited to small networks and does not convey neighboring geographic topology. The first web-service for undistorted reachability mapping visualizations is presented by Lightfood and Irving, which is called *Mapumental* today [14, 17]. It maps reachable urban space by shading inaccessible areas with an isochronic display.tool is limited to public transport only.

Further, FreeMapTools offers a Google-based application entitled *How Far Can I Travel* [7]. It computes an isochrone radius based on speed and travel time based on an actual road network. The computation of time-distances are performed client-side using multiple Google routing queries. However, this approach lacks performance and often fails due to timeouts. Similar to the *Travel Time Tube Map*, Meertens created *TimeMaps NL* specific for the Netherlands [18]. It distorts the base-map of the Netherlands based on public transport travel times and aligns the results along static circular isochrones. It enables the selection of different times of day to highlight different aspects of reachability during morning, noon, evening, and night times. The implementation, however, is targeted for the specifics of the Netherlands and does not scale for more detail. In [2] *IsoChrone.ch*, a web-based accessibility visualization for schedule-based public transport in Switzerland is presented. The display is limited to polygonal generalizations and does not support
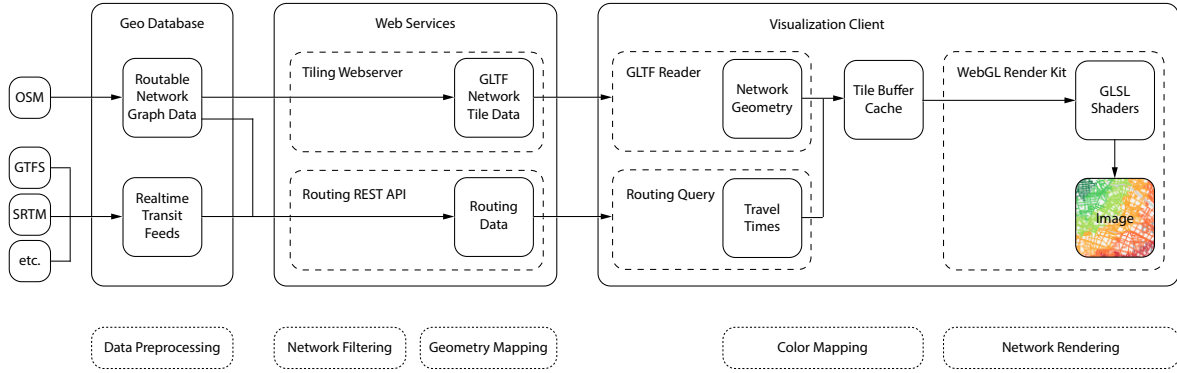
Figure 1: Conceptual overview of the presented web-based visualization pipeline including components and data flow.

multimodal travel. In [5], a first multimodal web-application is presented that enables logistics and land-use analytics with isochronic visual support. Further, *Mapnificent*, a first open-source, web-based reachability mapping service, computes isochrones on the fly and displays the reachable areas by shading out unreachable parts of the map [27]. Despite drawbacks in detail and accuracy, this approach performs client-side routing computations on simplified graph representations. Two alternate public transport accessibility displays are *TripTrop NYC* [24] and the successor *Transit Time NYC* [19], which visualize the subway transit times in New York City based on rectangular and hexagonal representations respectively. Due to massive amount of data, the resulting isochrones must be downloaded. The hexagonal approach counterbalances this limitation using a static grid displaying an average travel time per cell, thus lacks detail in presentation.

By extending the definition of reachability mapping and adding a further dimension, the *Isoscope* web application displays unified isochrone maps with time varying travel data [10]. Instead of using multiple isolines for different travel times, it uses multiple isolines for displaying accessibility information during different times of the day. Hence, this approach visualizes time-dependent spatial travel variance. Today, there are various services and components available for accessibility analytics on the web, among them the Travel Time Platform, the WalkScore Travel Time API, and the OpenRouteService accessibility analysis tools.

3 INTERACTIVE VISUALIZATION PIPELINE

Fig. 1 shows an conceptual overview of the system's architecture that follows a server-client model. The aim of this approach is to reduce client-side workload to a minimum. Therefore, all tasks from preprocessing, to filtering and mapping are performed on server-side. The back-end is based on the following three components. A *database server* frequently pulls updates from OSM, ensures sufficient data quality, and preprocesses the data for storage in a geo-database. A *tiling server* filters the transportation network from the geo-database and maps the focus data into a stack of pregenerated glTF-tiles that contain the complete network geometry. A *routing server* handles requests from the client and computes travel times based on user-defined parameters (e.g., start location, travel

modality, data operation mode). Further, a *web-mapping client* requests and loads the tiles containing the network geometry from the tiling server. Based on the respective parameters, it subsequently requests travel time information from the routing server and passes it along with the transportation network to a *WebGL-based renderer*. In addition thereto, the client contains a web-mapping framework which can display additional elements such as background tiles, map controls, scale or markers.

The purpose of a server providing abstract visualization data for the network-based accessibility mapping client is the elimination or minimization of processing steps in the mobile or web clients. Therefore, most of the stages of the visualization pipeline are prepared in the back-end. This includes data preprocessing, filtering, and mapping. The raw network data is acquired from OSM. In a preprocessing step, (1) the geo-data is pulled from OSM, (2) the feature attribution is normalized, (3) line features are extracted, and (4) a routable graph representation is generated. In the next step, the processed visualization data will be filtered according to the user selected parameters, e.g., origin node location, transportation media. In this case, the transportation network will be subdivided into suitable bounds, for instance by a selected maximum travel time, and unreachable segments will be removed. In addition, all nodes will be attributed with the required travel time from one or many starting locations.

Finally, the filtered focus data is required to be mapped to a geometrical representation. Usually, this step is closely related to a specific rendering engine used. However, the presented approach, prepares visualization objects in the backend without a render available. Therefore, the mapping stage assumes a WebGL-based renderer and prepares buffer objects containing vertices and indices suitable for GPU-based rendering. In addition, corresponding travel time data will be prepared in separate buffer objects to allow fast response without transmitting the full reference network geometry again. Such approach supports dynamic mapping (e.g., line-styles, color schemes) at run-time according to the user inputs without retransmission of data, similar to vector tiles. The data processing is transferred from client to server-side, similar to raster-tiling approaches. This results in high run-time performance with low latencies and the resulting geometries can be cached client-side.

(a) Maximum travel time: 120 min.   (b) Maximum travel time: 35 min.
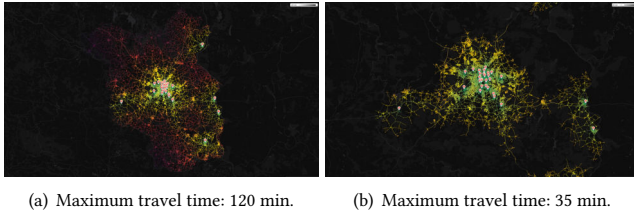
Figure 2: Visualization showing reachable fast food restaurants within 120 min (a) and 35 min (b) travel time using the car modality and the union data operator.
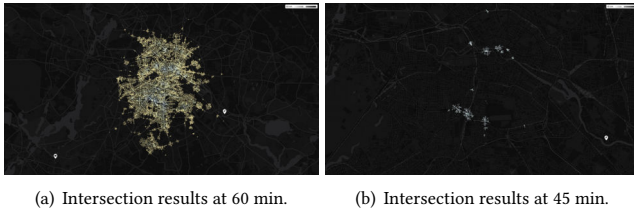

(a) Intersection results at 60 min.   (b) Intersection results at 45 min.

Figure 3: Displaying the intersecting areas for two different destination nodes used as indicator for suitable property locations.

The rendering is performed on dedicated GPU using WebGL and thus ensures real-time performance for geometrical complex data sets. For a full network mapping and rendering the client overall performance is within the range of approx. 100 ms. In addition to rendering, the web application provides interaction techniques. Depending on the technique, it is desirable to avoid a complete tile reload and thus repeat the complete visualization process on both the backend and frontend. The mapping of travel time to color is performed by a fragment shader program. Given the maximum travel time selected by the user, the individual travel time attributes obtained per fragment after line rasterization, are normalized and mapped to 1D texture coordinates for sampling. Using these coordinates, a 1D texture is sampled accordingly with texture filtering disabled.

4 APPLICATION EXAMPLES

Business Location Finder. Fig. 2 shows two exemplary visualizations for finding business locations (e.g., fast food restaurants) that are reachable by car in certain amount of time. This demonstrates the general use case of location intelligence: given different types and instances of built infrastructures, compute reachability coverage. Thirty-two locations of a fast food franchise are automatically placed as destinations on the map. The travel times to each restaurant are computed with the union analysis operator. This allows to display the shortest time required to reach the closest franchise destinations with respect to each node in the network.

Property Market Analysis. For an urban property analysis use case, an intersection operator is applied, that computes the shortest travel times to all destination nodes and displays the longest travel
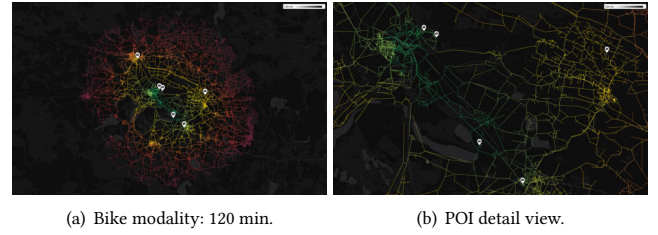

(a) Bike modality: 120 min.   (b) POI detail view.

Figure 4: Visualization of an planned bicycle journey with two hours average travel time between selected points-of-interests (POI).

time required to the most distant destination node for reach origin. Here, two relevant destination-marker nodes are placed on the map: a person who (1) studies in a suburban town and (2) works in city is searching for a suitable apartment in terms of reachability using public transportation. Presenting the city area with a maximum selected travel time of 60 minutes by transit (Fig. 3(a)) shows a clear intersection in the city center. Increasing the zoom level reveals a more detailed display. Reducing the maximum travel time to 45 min (Fig. 3(b)) highlights the optimal reachable areas close to public-transit hubs.

Spare-time Activity Planning. Fig. 4 shows exemplary results for using the presented technique for spare-time activity planning in the field of individual tourism. In general, MA can be used to analyze possible destinations with respect to required travel time and travel expenses. For example, given a starting point: (1) travel time is evaluated for a given transportation mode and categorized travel time zones are shown on a map; or (2) find reachable areas or landmarks. Also, the computation of route characteristics for a given target represents a use case. For a search free of target, the average analysis operator is used to identify reachable POIs in the selected region. Our techniques enables the display of a detailed bike network. A maximum travel time of 120 min (Fig. 4(a)) shows a detailed network of bike paths. At least four of the pre-selected POI can be reached within 60 min of travel time (Fig. 4(b)).

5 CONCLUSIONS

This paper presents a web-based approach for mapping and rendering of transportation networks for mobility analytics using reachability maps. The presented prototype renders transportation networks for web-based mobility analytics outside an GIS expert-system. It does not require any optimizations of the network such as filtering, generalization, or simplification and enables users with dynamic, client-side adjustments of the visualization parameters.

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